Nuclear Science Training Course with Nucleonica

Mass Activity Converter

Raymond Dreher / Joseph Magill

Nucleonica GmbH,
c/o European Commission,
76344 Eggenstein-Leopoldshafen, Germany

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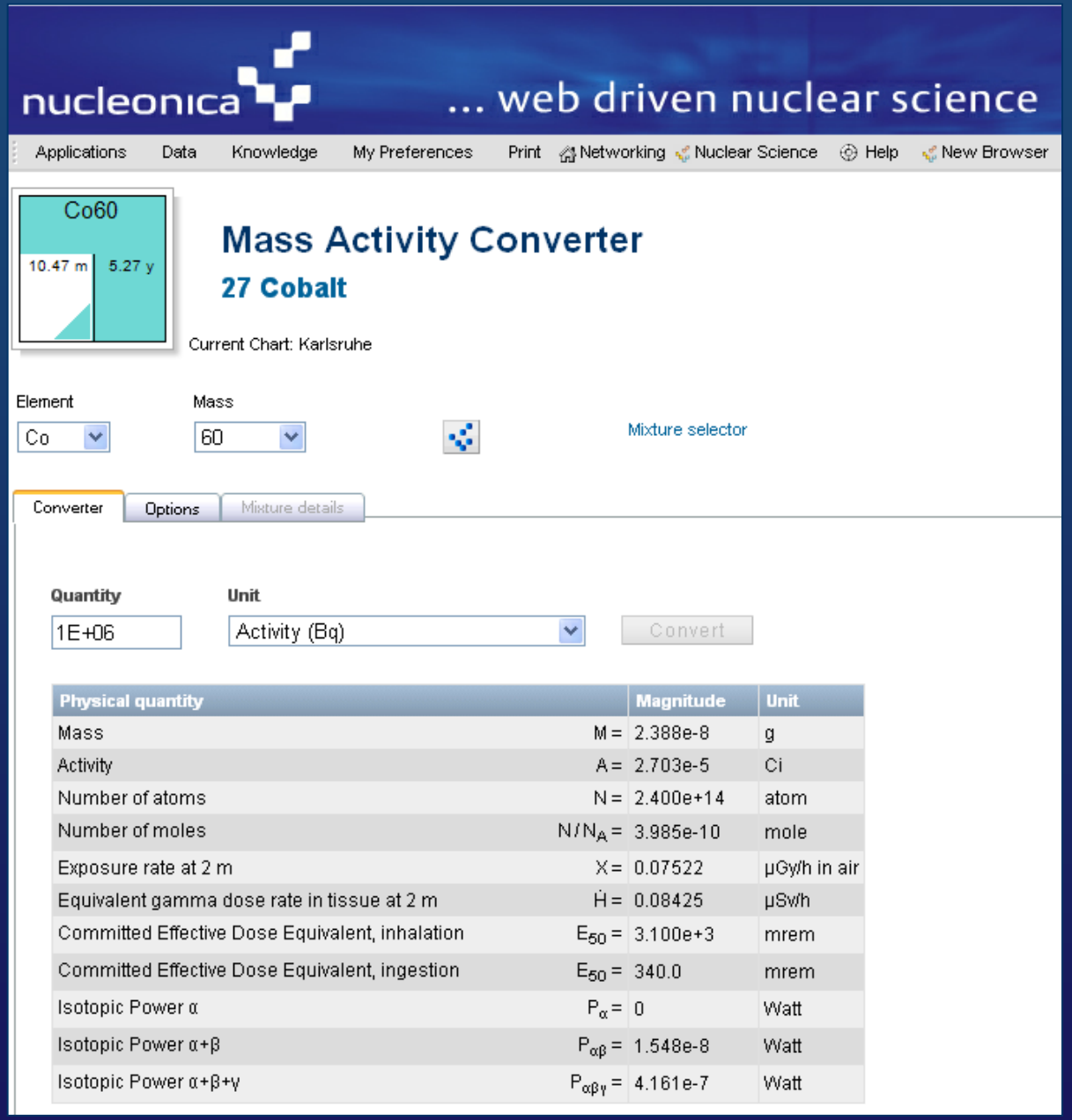
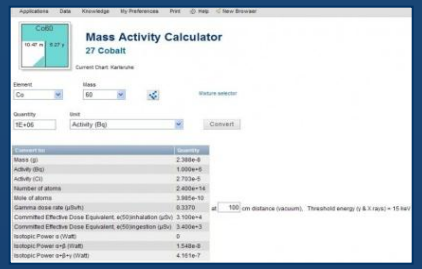


Learning Objectives



• To become familiar with basic radiological units becquerel (Bq), curie (Ci), sievert (Sv), etc.

• To become familiar with basic radiological quantities such as activity, specific activity, dose rate, etc.

• To understand the relationships between the basic units

• To get to know how to use the Mass Activity Convertor module in Nucleonica to convert between different units. This requires familiarity with the Glossary, Help, Calculator

• To strengthen the above understanding through a series of problems and exercises.

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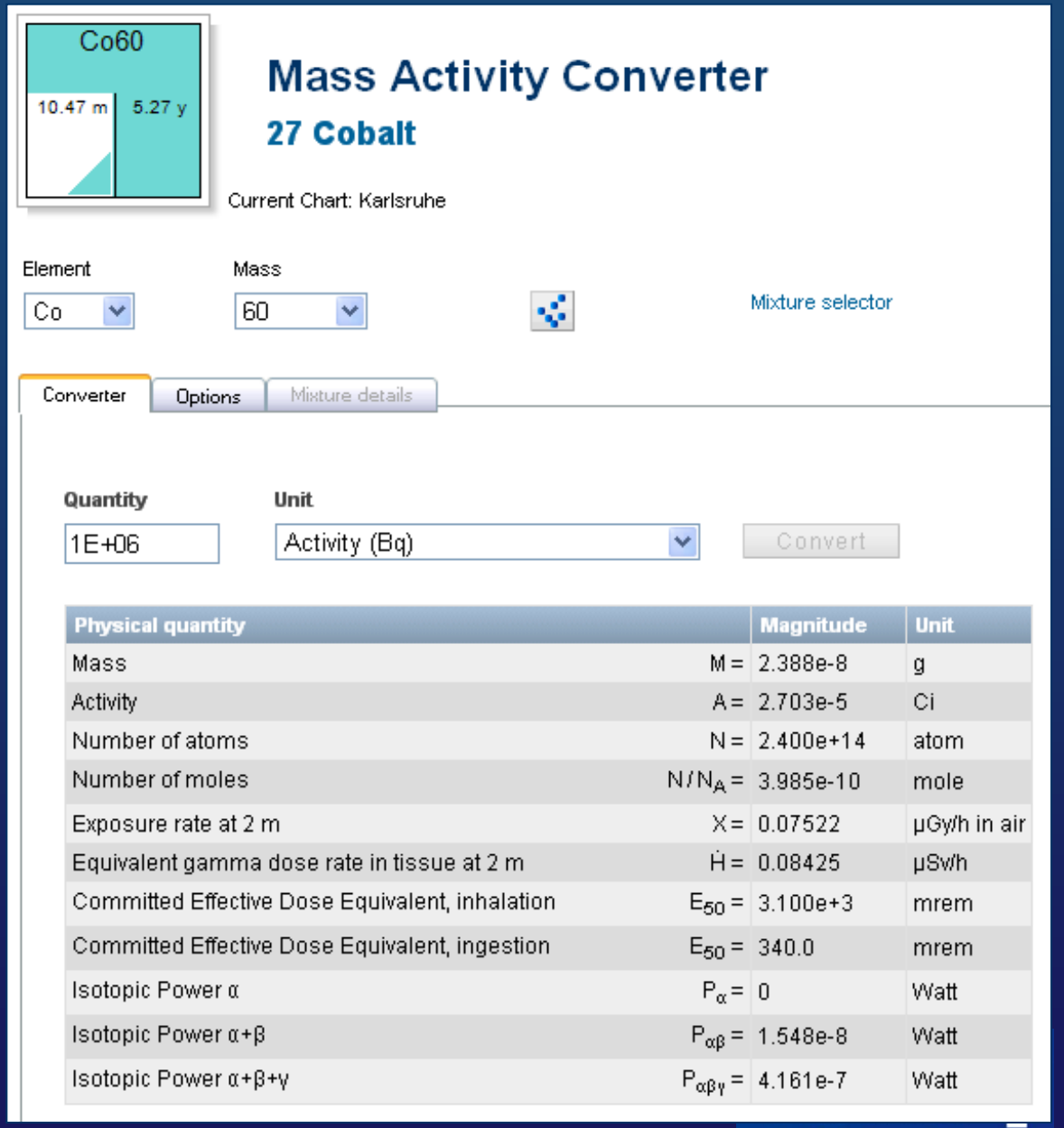
The mass activity calculator is a popular tool for conversion between different physical quantities (e.g. mass, activity, number of atoms, etc.).

- external and internal dosimetry quantities such as the gamma dose rate (where the distance is required)

- the committed effective doses for inhalation and ingestion.

- the amount of heat generated – isotopic power – through radioactive decay for α, α+β, and α+β+γ.

In the this example, the nuclide Co-60 is selected. A different nuclide can be selected from the element and mass drop-down menus. The default source strength is 1 MBq. In the unit drop-down menu, the source strength is shown in becquerel (Bq), curie (Ci), number of atoms, etc. The user can also select a previously defined nuclide mixture (by clicking on the Mixture selector). Further information is given in the Nucleonica wiki.



Physical quantity		Magnitude	Unit
Mass	M =	2.388e-8	g
Activity	A =	2.703e-5	Ci
Number of atoms	N =	2.400e+14	atom
Number of moles	N/N_A =	3.985e-10	mole
Exposure rate at 2 m	X =	0.07522	µGy/h in air
Equivalent gamma dose rate in tissue at 2 m	$\dot{H}$ =	0.08425	µSv/h
Committed Effective Dose Equivalent, inhalation	E_{50} =	3.100e+3	mrem
Committed Effective Dose Equivalent, ingestion	E_{50} =	340.0	mrem
Isotopic Power α	P_α =	0	Watt
Isotopic Power α+β	$P_{\alpha\beta}$ =	1.548e-8	Watt
Isotopic Power α+β+γ	$P_{\alpha\beta\gamma}$ =	4.161e-7	Watt

Help: Nucleonica Wiki…

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Help:Mass Activity Converter

Level: Introductory, Intermediate

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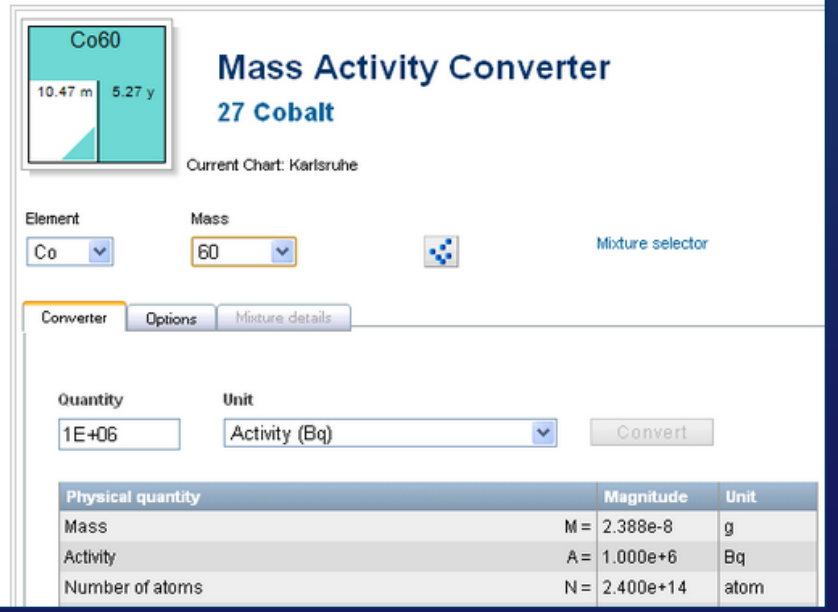
Nucleonica's Mass Activity Converter

The mass activity converter is a popular tool for conversion between different physical quantities (e.g. mass, activity, number of atoms, etc.). A particularly useful feature is that in addition to single nuclides, the mass activity calculator can also be applied to nuclide mixtures. These nuclide mixtures can be created with the Nuclide Mixtures module. The Convert box shows the full list of quantities. In addition to the standard list (mass, activities, etc.), conversions can also be made using:

- external and internal dosimetry quantities such as the gamma dose rate (where the distance is required)
- the committed effective doses for inhalation and ingestion.
- the amount of heat generated – isotopic power – through radioactive decay for α, α+β, α+β+γ.

In the above example, the nuclide Co-60 is selected. A different nuclide can be selected from the element and mass drop-down menus. The default source strength is 1 MBq. In the unit drop-down menu, the source strength is shown in becquerel (Bq), curie (Ci), number of atoms, etc. The user can also select a



Basic Quantities and Relations

In this section, the basic relationships between number of atoms, mass, and activity, are developed. From these basic quantities, additional quantities such as the gamma dose rate, the effective doses for inhalation and ingestion and the isotopic powers can be obtained.

For an amount of material with mass in grams given by $Mass(g)$, the number of atoms N is given by

$$\frac{N}{N_A} = \frac{Mass(g)}{M} \quad \text{or} \quad N = Mass(g) \cdot \frac{N_A}{M}$$

Where N_A is Avogadro's number or Avogadro's constant ($N_A = 6.002214179 \text{x} 10^{23}$), and M is the atomic mass of the nuclide. This basic relationship follows from the fact that 1 mole of any material contains Avogadro's number of atom.

The conversion of number of atoms to the number of moles is given by

$$\text{Number of moles} = \frac{N}{N_A}$$

The conversion from number of atoms to activity, and vice versa, is obtained using

$$Activity(Bq) = k \cdot N = \ln 2 \cdot N / \tau$$

$$Activity(Ci) = Activity(Bq) / 3.7 \cdot 10^{10}$$

Where k, and τ are the decay constant and half-life respectively of the nuclide. Combining the above relations, it follows that the relation between activity and mass is given by

$$Activity(Bq) = (\ln 2 / \tau) \cdot Mass(g) \cdot N_A / M$$

Derived Quantities

From the activity A, additional important quantities such as the gamma dose rate, the committed effective doses and the isotopic powers can be derived. The relations used in the Mass Activity Calculator are given below. For more details on the meaning and derivation of these quantities, the reader should follow the links.

The gamma dose rate in tissue, dH/dt, (follow the link for the derivation) is given by

$$\frac{dH}{dt} = A/(4\pi R^2) \cdot \sum_i (E_i \cdot P_i \cdot (\mu_l / \rho)_i^{tis})$$

From the above relation, it can be seen that the gamma dose rate depends on the distance R from the source. For this reason, for the evaluation of the gamma dose rate, the distance must also be specified. A default distance of 100 cm is used. In addition, the threshold energy must also be specified. The default value of the threshold energy is 15 keV. Other quantities required for the calculation are the energies E_i and emission probabilities P_i of the radiation, and the mass absorption coefficient $(\mu/\rho)_i^{tis}$ in tissue. The summation index i refers to all the individual gamma and x-ray energies.

The committed effective doses are given by

$$\textit{Committed effective dose for inhalation}, \quad E_{inh}(50) = e_{inh}(50) \cdot Activity(Bq)$$
$$\textit{Committed effective dose for ingestion}, \quad E_{ing}(50) = e_{ing}(50) \cdot Activity(Bq)$$

Finally, the isotopic power is given by

$$\textit{Isotopic Power } (\alpha) = A \cdot |E_\alpha|$$
$$\textit{Isotopic Power } (\alpha + \beta) = A \cdot |E_\alpha + E_\beta|$$
$$\textit{Isotopic Power } (\alpha + \beta + \gamma) = A \cdot |E_\alpha + E_\beta + E_\gamma|$$

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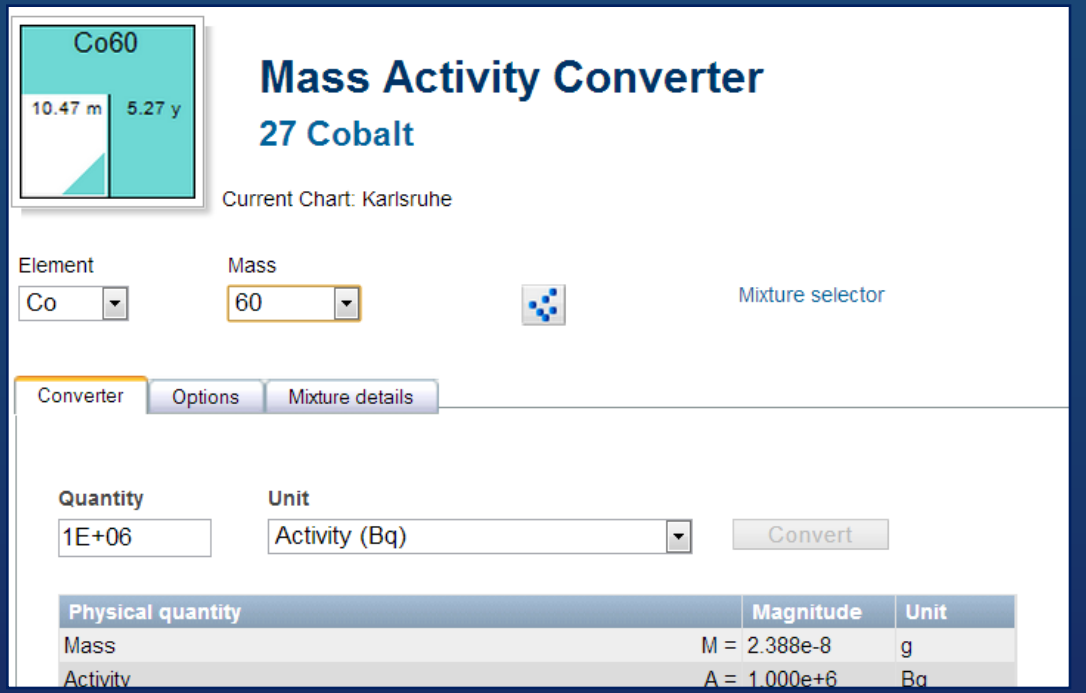
Nuclide Selector

In the Mass Activity Convertor, the nuclide Co-60 is selected by default. A different nuclide can be selected from the element and mass drop-down menus.

The Nuclide Chart icon shows the location of the selected nuclide on the nuclide chart. To the right of this, the nuclide mixture link can be used to select a nuclide mixture.

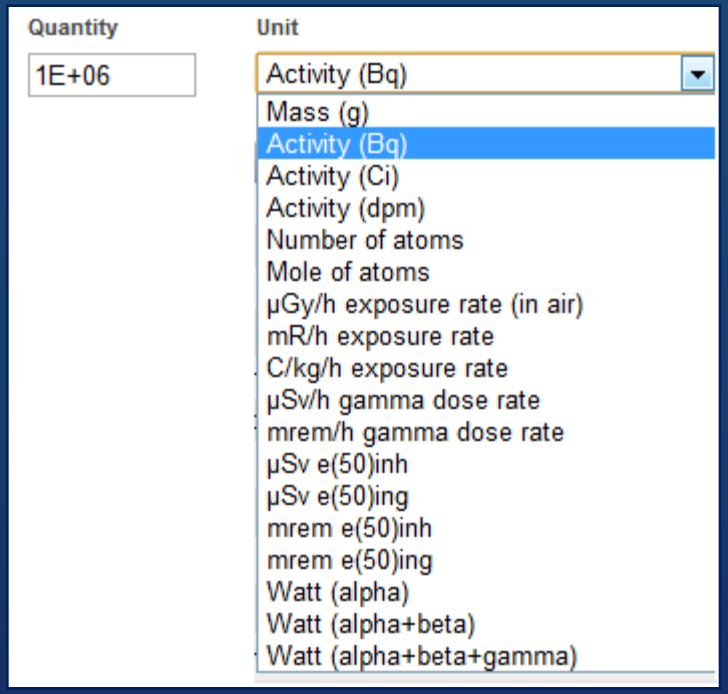
The source strength can be specified by using the drop-down menus (see the following section). The default source strength is 1 MBq.

In the Unit/Quantity drop-down menus, the source strength is shown in becquerel (Bq), curie (Ci), number of atoms, etc. This can then be converted to other units.



Unit/Quantity Selector

The input unit can be changed in the Unit drop down menu. The default unit is Bq. Had the value Ci been selected, on pressing the Convert button, the corresponding values in grams, Bq, number of atoms etc. are shown in the Convert to/Quantity table.



Once the unit and quantity have been selected in the Unit/Quantity Selector, the source strength in other units is given in the physical quantity table, by pressing the Convert button. The results are shown for 1 MBq Co-60.

Physical quantity		Magnitude	Unit
Mass	M =	2.388e-8	g
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Number of atoms	N =	2.400e+14	atom
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Isotopic Power α	P_α =	0	Watt
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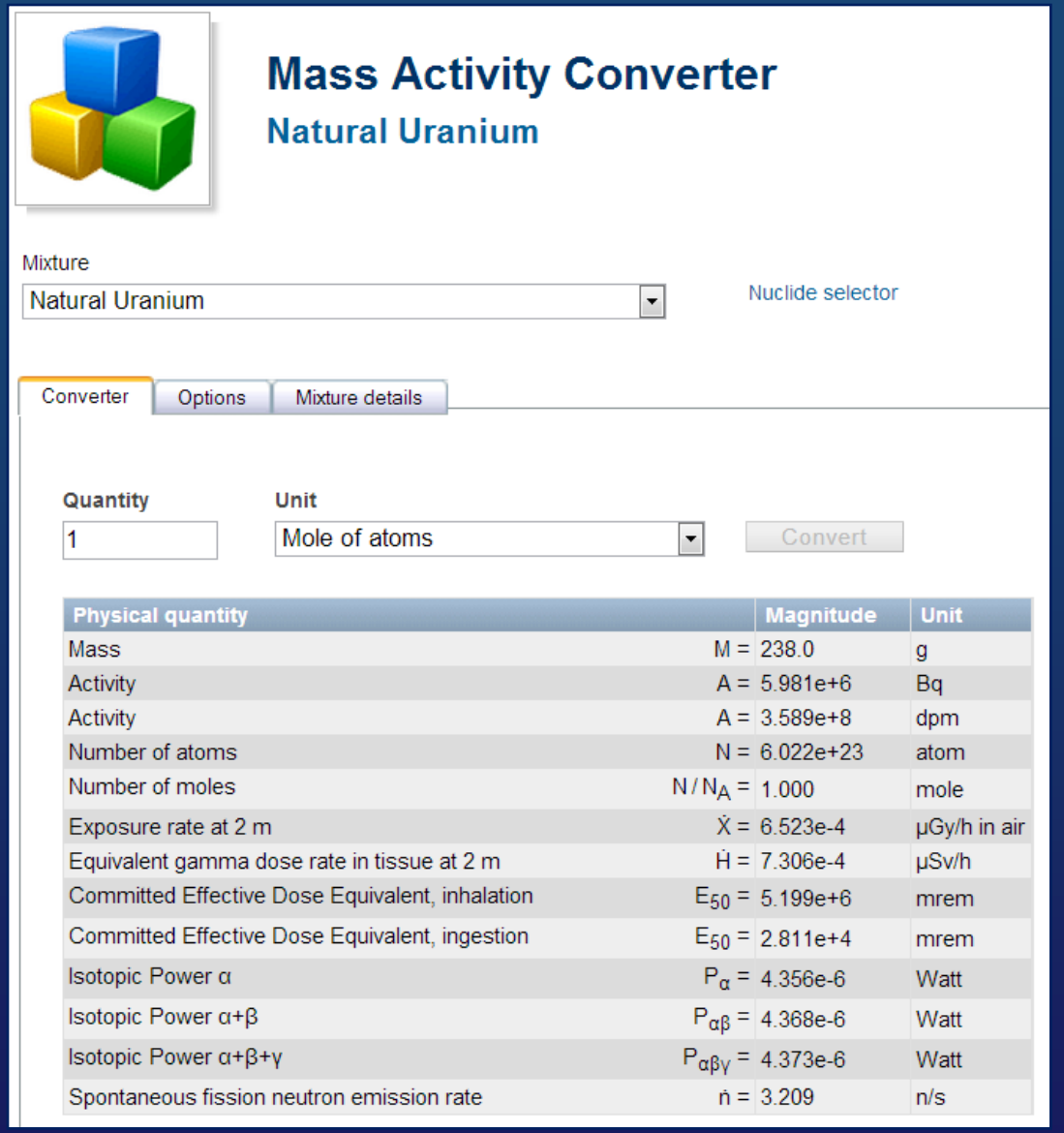
Isotopic Power α+β+γ	$P_{\alpha\beta\gamma}$ =	4.161e-7	Watt

Nuclide Mixtures

The mass activity calculator can also be used for nuclide mixtures. In the diagram shown, the nuclide mixture “natural uranium” has been selected. This mixture has been previously created in the Nuclide Mixtures module for 1 mole (of atoms) of natural uranium containing

0.9927 mole U-238,
7.114×10^{-3} mole U-235 and
5.310×10^{-5} mole U-234.

As can be seen, even 1 mole of atoms of natural uranium, with a mass of 238 gram and activity of almost 6 MBq (without daughters), has a negligible gamma dose rate and heat emission rate (isotopic power).



Physical quantity		Magnitude	Unit
Mass	M =	238.0	g
Activity	A =	5.981e+6	Bq
Activity	A =	3.589e+8	dpm
Number of atoms	N =	6.022e+23	atom
Number of moles	N / N_A =	1.000	mole
Exposure rate at 2 m	$\dot{X}$ =	6.523e-4	µGy/h in air
Equivalent gamma dose rate in tissue at 2 m	$\dot{H}$ =	7.306e-4	µSv/h
Committed Effective Dose Equivalent, inhalation	E_{50} =	5.199e+6	mrem
Committed Effective Dose Equivalent, ingestion	E_{50} =	2.811e+4	mrem
Isotopic Power α	P_α =	4.356e-6	Watt
Isotopic Power α+β	$P_{\alpha\beta}$ =	4.368e-6	Watt
Isotopic Power α+β+γ	$P_{\alpha\beta\gamma}$ =	4.373e-6	Watt
Spontaneous fission neutron emission rate	$\dot{n}$ =	3.209	n/s

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Exercises Mass Activity Converter

1. **Calculate the specific activities of C-14 and S-35?** (1.7E11 Bq/g (4.5 Ci/g), 1.6E15 Bq/g (4.3E4 Ci/g)).
2. **The activity of Sr-90 is 18,000 transformations per minute. What is the mass of Sr-90?** (mass = 5.87E-11g).
3. **Six grams of carbon from a piece of wood found in an ancient temple are analyzed and found to have an activity of 10 transformations per minute per gram of carbon. How many atoms of C-14 are present in the sample and what is their mass?** (2.6E11 atoms, mass = 6.0E-12 g)
4. **What is the dose rate from a 100 MBq source of Co-60 at 2m distance**? (8.4 µSv/h)
5. **How many grams of Y-90 are in secular equilibrium with 1 mg Sr-90?** (0.25 µg)
6. **The environmental burden of C-14 is as follows: in the atmosphere 4 MCi, in plants 13 MCi, in the oceans 240 MCi. What are the masses of C-14 in a) the atmosphere, b) in plants, c) in the oceans?**

   (893 kg, 2.9 metric tonnes, 53.6 tonnes)

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Exercises Mass Activity Converter

5. The concentration of potassium (K) in humans is about 1.7 g/kg. What mass of potassium does an average person (weight 80 kg) contain? (136 g).

- **What is the atomic weight of potassium?** Hint: see the sample mixture in the Nuclide Mixtures (39.0983)
- **What is the total number of atoms of potassium?** (2.09E24 atoms)
- **What is the total number of atoms of K-40?** (2.45E20 atoms K-40).
  What is the abundance of K-40? (0.0117 atom%)
- **What is the mass and activity of K-40 in this person?** (1.62E-2 g, 4.2 kBq).

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